Out-Diffusion and Precipitation of Copper in Silicon

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INTRODUCTION

The use of copper for metallic interconnects in ULSI technology has revived the interest in the precipitation kinetics of copper in silicon. We have investigated copper in p- and n-type Float Zone (FZ) and Czochralski (CZ) -silicon of varying doping concentration after copper diffusion and quench leading to contamination levels in the range of $10^{15}cm^{-3}$ to $10^{17}cm^{-3}$. While the interstitial copper concentration was measured with Transient Ion Drift (TID), the precipitated copper concentration was detected by X-Ray Fluorescence (XRF) at the Advanced Light Source, beamline 10.3.1. The existence of the precipitates as well as their morphology was investigated by Transmission Electron Microscopy (TEM). Deep Level Transient Spectroscopy (DLTS) and Minority Carrier Transient Spectroscopy (MCTS) was used to electrically characterize the defects.

In n-type FZ-silicon no dissolved interstitial copper was detected with TID after in-diffusion and quench. However, the precipitated copper, as measured with XRF, was found to be close to the copper solubility at the in-diffusion temperature. These results are shown below in Figure 1.

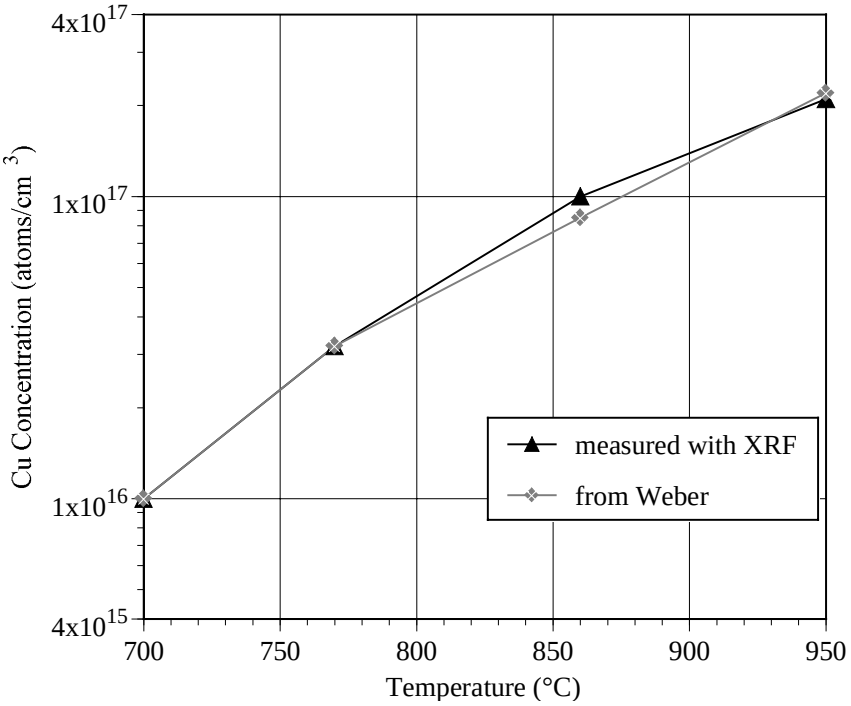

Figure 1: Cu concentration in n-type silicon as measured with XRF on beamline 10.3.1 at the Advanced Light Source. The results from Weber, [1], are a compilation of results obtained with neutron activation analysis.

Conversely, in p-type FZ-silicon, interstitial copper was observed after quench with TID, and only a few copper precipitates were observed with TEM if the copper contamination was chosen below a certain critical level, $\approx 10^{16} cm^{-3}$. At higher contamination levels, precipitation prevails and the total concentration of copper, as measured with XRF, reaches the solubility level at the diffusion temperature. Despite the difference in the precipitation kinetics of p- and n-type silicon, the precipitates found in p-type form the same thin platelets as are known after quench in n-type. Also, the MCTS spectra of the copper precipitates in p-type is found to be similar in shape than the copper related DLTS plateau in n-type ranging from E_C-0.15eV to E_C-0.35eV, [2]

Analysis of the experimental data suggests that the copper behavior is dominated by bulk precipitation in n-type silicon and by out-diffusion in p-type silicon. If the concentration of the positively charged copper exceeds the acceptor concentration, type inversion may occur. Furthermore, we discuss a possible Fermi level effect on the growth mechanism of the copper precipitates. The Fermi level position given by an interstitial copper concentration of $10^{16} cm^{-3}$ coincides with the charge neutrality level of the copper precipitates [3-5]. Thus, precipitation of copper with concentrations below this critical level could be inhibited by Coulomb repulsion of the positively charged interstitial copper ions and the as well positively charged precipitates, and out-diffusion will be dominant. However, at copper concentrations above this critical level, the precipitates will be neutral or negatively charged and precipitation of the supersaturated copper can occur unrestricted.

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